













# TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

-  **Technology Focus**
-  **Electronics/Computers**
-  **Software**
-  **Materials**
-  **Mechanics/Machinery**
-  **Manufacturing**
-  **Bio-Medical**
-  **Physical Sciences**
-  **Information Sciences**
-  **Books and Reports**



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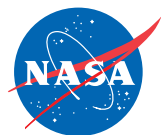
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## Technology Focus: Data Acquisition

### Program Merges SAR Data on Terrain and Vegetation Heights

NASA's Jet Propulsion Laboratory, Pasadena, California

X/P Merge is a computer program that estimates ground-surface elevations and vegetation heights from multiple sets of data acquired by the GeoSAR instrument [a terrain-mapping synthetic-aperture radar (SAR) system that operates in the X and P bands]. X/P Merge software combines data from X- and P-band digital elevation models, SAR backscatter magnitudes, and interferometric correlation magnitudes into a simplified

set of output topographical maps of ground-surface elevation and tree height.

For computational efficiency, inversions are performed by use of lookup tables. The program performs calibrations to remove biases from output estimates, calibrates interferometric correlation magnitudes by accounting for geometric and radiometric errors, differentiates between surface and vegetated

areas, and, on a pixel-by-pixel basis, selects the lookup table corresponding to the best user-specified inversion approach.

*This program was written by Paul Siqueira, Scott Hensley, Ernesto Rodriguez, and Marc Simard of Caltech for NASA's Jet Propulsion Laboratory.*

*This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40268.*

### Using G<sup>4</sup>FETs as a Data Router for In-Plane Crossing of Signal Paths

Cross-talk is low enough that integrity of signals could be preserved.

NASA's Jet Propulsion Laboratory, Pasadena, California

Theoretical analysis and some experiments have demonstrated that silicon-on-insulator (SOI) 4-gate transistors of the type known as G<sup>4</sup>FETs could be efficiently used for in-plane crossing of signal paths. Much of the effort of designing very-large-scale integrated (VLSI) circuits is focused on area-efficient routing of signals. The main source of difficulty in VLSI signal routing is the requirement to prevent crossing, in the same plane, of wires that are meant to be kept electrically insulated from each other. Consequently, it often becomes necessary to design and build VLSI circuits in multiple layers with vias (connections between conductors in different layers at selected locations). Suitable devices that would prevent, or at least sufficiently suppress, undesired electrical coupling (cross-talk) between wires crossing in the same plane would enable compact, simpler implementation of complex interconnection networks with in-plane crossings that, heretofore, have not been possible in VLSI circuitry. The use of G<sup>4</sup>FETs as in-plane signal-crossing devices or routers, in combination with the use of G<sup>4</sup>FETs as universal programmable logic gates, would create opportunities for reducing complexity in VLSI design.

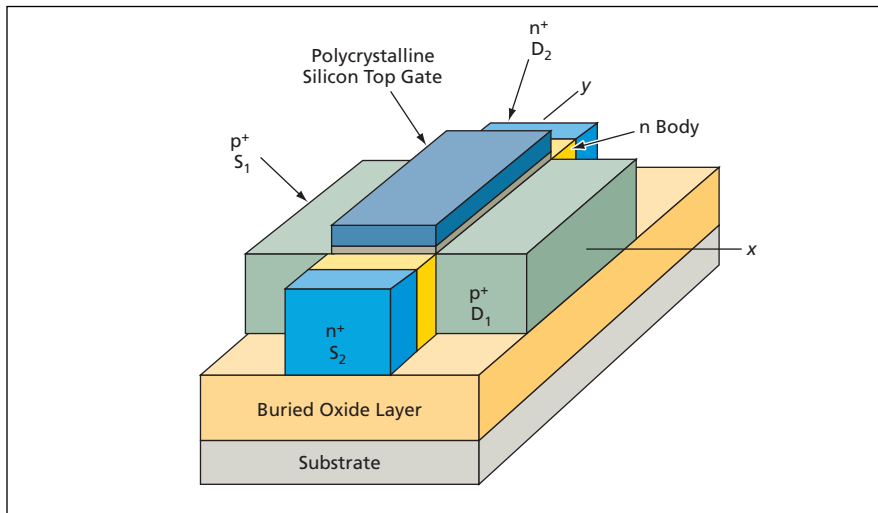


Figure 1. The G<sup>4</sup>FET consists of a p-channel inversion-mode MOSFET (including source S1 and drain D1) for current flowing in the x direction and an accumulation-mode n-channel MOSFET (including source S2 and drain D2) for current flowing in the y direction. The gate, body and substrate are common to both transistors.

A G<sup>4</sup>FET, depicted in simplified form in Figure 1, has the same basic structure as does a prior SOI cross-MOSFET (metal oxide/semiconductor field-effect transistor), though the cross-MOSFET is somewhat wider. The cross-MOSFET consists essentially of an inversion-mode and an accumulation-mode MOSFET that share gate and substrate terminals

and are oriented perpendicularly to each other. The prior use of the cross-MOSFET involved sequential operation of the inversion-mode and accumulation-mode MOSFETs. In contrast, the use of the G<sup>4</sup>FET as an in-plane router involves the simultaneous operation of the inversion-mode MOSFET in one in-plane direction and the accumulation-

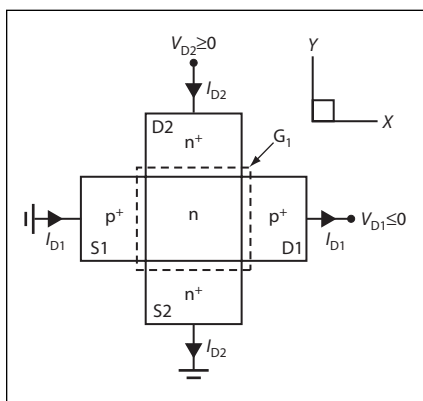


Figure 2. The DC Configuration of the G<sup>4</sup>FET of Figure 1 is helpful in understanding the ability of the device to function as a router.

mode MOSFET in the orthogonal in-plane direction.

Figure 2 schematically shows the DC configuration of the G<sup>4</sup>FET relevant to its use as a signal router. The drain (D1) of the inversion-mode p-channel MOSFET is biased to  $V_{D1}$ , the drain (D2) of the accumulation-mode n-channel MOSFET is biased to  $V_{D2}$ , and the source terminals (S1 and S2) of both transistors are grounded.

The two drain currents,  $I_{D1}$  and  $I_{D2}$ , are perpendicular to each other and can flow at the same time.  $I_{D1}$  depends on minority charge carriers and flows at the surface in the  $x$  direction, while  $I_{D2}$  depends on majority carriers and flows at the mid-depth of the silicon film in the  $y$  direction. Surface holes and bulk electrons do not recombine because front-gate-induced depletion region isolates them. The top gate can modulate both drain currents —  $I_{D1}$  through regular MOS action and  $I_{D2}$  through vertical-depletion-width modulation.  $I_{D1}$  and  $I_{D2}$  can also weakly modulate each other — an undesirable effect in that it results in some cross-talk. In operation of the G<sup>4</sup>FET as a router, S1 and S2 would be disconnected from ground and signals would be applied to D1 and D2 for the purpose of coupling them to S1 and S2, respectively. In experiments on a G<sup>4</sup>FET that had not been optimized for use as a router, square-wave signals of various frequencies from 1 kHz to 1 MHz were applied to D1 and D2 simultaneously and were shown to be coupled to S1 and S2, respectively, as desired. Cross-talk was ob-

served, but was found to be within conventional noise margins. This result supports the expectation that the integrity of digital signals could be preserved when using G<sup>4</sup>FETs as routers.

*This work was done by Amir Fijany, Farrokh Vatan, Mohammad Mojarradi, Nikzad Toomarian, Travis Johnson, Elizabeth Kolawa, Benjamin Blalock, Sorin Cristoloveanu, Suheng Chen, and Kerem Akarvardar of Caltech for NASA's Jet Propulsion Laboratory.*

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*Refer to NPO-41827, volume and number of this NASA Tech Briefs issue, and the page number.*

## Two Algorithms for Processing Electronic Nose Data

Vapors are identified and their concentrations are estimated.

*John F. Kennedy Space Center, Florida*

Two algorithms for processing the digitized readings of electronic noses, and computer programs to implement the algorithms, have been devised in a continuing effort to increase the utility of electronic noses as means of identifying airborne compounds and measuring their concentrations. One algorithm identifies the two vapors in a two-vapor mixture and estimates the concentration of each vapor (in principle, this algorithm could be extended to more than two vapors). The other algorithm identifies a single vapor and estimates its concentration.

An electronic nose consists of an array of sensors, all of which respond to a variety of chemicals. By design, each sensor is unique in its responses to these chemicals: some or all of the sensitivities of a given sensor to the various vapors differ from the corresponding sensitivities of another sensor. The two algorithms exploit these sensitivities and the differences among them.

The validity of the two-vapor algorithm depends on the validity of the assumption that, of all the vapors of inter-

est, no more than two of them are present at the time of measurement. This algorithm utilizes the following mathematical model of the response of a given sensor to a given pair of vapors:

$$z = A + (Bx^C + Dy^E)^F,$$

where  $z$  is the sensor response,  $x$  and  $y$  are the concentrations of the two vapors, and parameters  $A$  through  $F$  are obtained by least-squares best fit of sensor responses to known concentrations of the individual vapors and to known concentrations of mixtures of the two vapors. The reason for choosing this model is that this research has shown it to be the best for mixtures of vapors. The model equation defines a response surface of the given sensor for the given pair of vapors.

Given the responses of an electronic nose to an unknown single vapor or two-vapor mixture, the first step of this algorithm is to calculate the difference between (1) the actual response of each sensor and (2) the model response of the sensor for an assumed

pair of vapors. This calculation yields an error surface for the given sensor for the given two vapors. Next, the error surfaces thus calculated for all the sensors in the array are combined to obtain an error surface for the electronic nose with respect for the assumed two vapors. Next, the process as described thus far is performed for a different pair of vapors. The process is repeated until error surfaces for all possible pairs of vapors have been calculated.

It is necessary to find the minimum point on the electronic-nose error surface for each pair of vapors. In the present version of the algorithm, this is done by sampling values on a grid and selecting the sample that has the minimum value. In a subsequent enhanced version of the algorithm, a more sophisticated technique (e.g., gradient descent) might be used to find the minimum. The pair of vapors for which the electronic-nose error surface has the lowest minimum value is deemed to be identified as the vapor pair sensed by the electronic nose. Provided that this identification is cor-



rect, the concentrations of the two vapors are the coordinates of the location of the minimum on the error surface for that pair.

The validity of the single-vapor algorithm depends on the validity of the assumption that, of all the vapors of interest, only one is present at the time of measurement. This algorithm utilizes the following mathematical model of the response of a given sensor to a single vapor:

$$z = A(1 - e^{Bx}),$$

where  $z$  is the sensor response,  $x$  is the concentration of the vapor, and param-

eters  $A$  and  $B$  are obtained by least-squares best fit of sensor responses at known values of  $x$ . This model is appropriate because it gives both the expected zero response at zero concentration and saturation response at high concentration.

The first step of the single-vapor algorithm is to identify the vapor by applying standard statistical pattern-recognition techniques to the responses of the electronic nose. Assuming that the vapor has been correctly identified, one could, in principle, estimate the concentration by applying the inverse of the model to the responses of all sensors in the nose. The question is how

best to utilize the readings of all the sensors in the nose to obtain the best estimate. Research has answered the question: the best estimate is obtained by inverting the reading of a single sensor known to be best for the vapor that has been identified. Accordingly, the algorithm chooses the sensor found to be best for the identified vapor and calculates the concentration from the reading of that sensor.

*This work was done by Rebecca Young of Kennedy Space Center and Bruce Linnell and Barbara Peterson of ASRC Aerospace. Further information is contained in a TSP (see page 1).*

KSC-12725/20

## Radiation-Tolerant Dual Data Bus

**Dedicated hardware and software would detect radiation-induced upsets on either of two buses.**

*Marshall Space Flight Center, Alabama*

An architecture, and a method of utilizing the architecture, have been proposed to enable error-free operation of a data bus that includes, and is connected to, commercial off-the-shelf (COTS) circuits and components that are inherently susceptible to single-event upsets [SEUs (bit flips caused by impinging high-energy particles and photons)]. The architecture and method are applicable, more specifically, to data-bus circuitry based on the Institute for Electrical and Electronics Engineers (IEEE) 1394b standard for a high-speed serial bus.

The architecture and method call for the use of two IEEE 1394b buses that nominally carry identical data signals. It

is assumed that at all times, at least one of the buses is "good" in the sense that it carries complete and correct data signals. Electronic hardware and software operating at each receiving location (node) along the bus would select the data arriving on the "good" bus while ignoring possibly corrupted data arriving on the other bus, which could be operating under latchup or an SEU including, possibly, a single-event functional interrupt (SEFI, an SEU that changes a control logic level, causing the affected circuit to enter an erroneous operational mode or logic state, the recovery from which must be effected through a power reset or other specified procedure).

The hardware at each node would include network-interface circuits plus special-purpose circuits denoted circumvention circuits. Among the circumvention circuits would be bus-management circuits and watchdog timers that would monitor the network interface chips. Use of software would examine the outputs of these circumvention monitoring circuits to detect SEUs (including SEFIs). Latchups in radiation-sensitive IEEE 1394b bus components would be detected by current-sensing circumvention circuits. Upon detection of an SEU (including an SEFI) or latchup, other circumvention circuits would restore correct operation by turning off, then turning back on, then reinitializing the affected bus circuitry, all within a predetermined, acceptably short time.

The software would reside in a dedicated radiation-hard microcontroller or shared radiation-hard single-board computer (SBC).

*This work was done by Gary A. Kinstler of The Boeing Co. for Marshall Space Flight Center.*

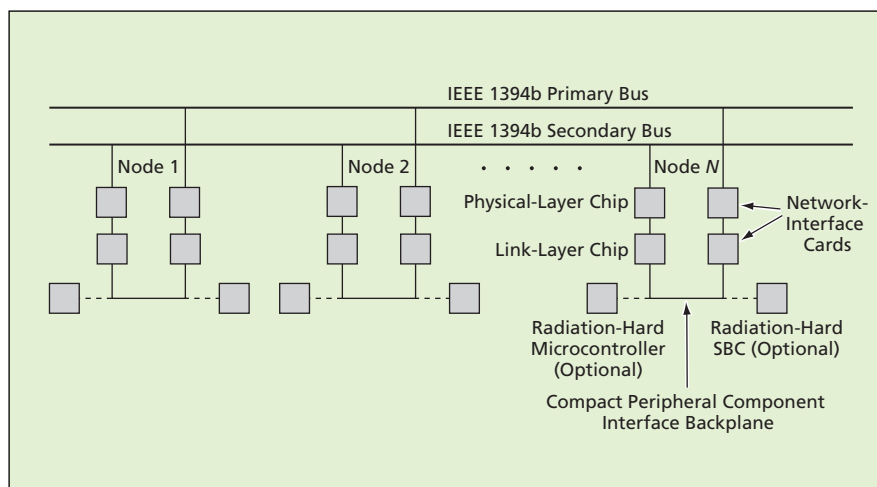
*Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)} to The Boeing Co. Inquiries concerning licenses for its commercial development should be addressed to:*

*The Boeing Co.*

*5301 Bolsa Ave.*

*Huntington Beach, CA 92647-2099*

*Refer to MFS-32132, volume and number of this NASA Tech Briefs issue, and the page number.*



**Two IEEE 1394b Buses** would nominally carry identical data signals. The network interface circumvention circuits, with the help of the microcontrollers, would detect radiation-induced upsets on either bus.

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## General-Purpose Front End for Real-Time Data Processing

*NASA's Jet Propulsion Laboratory, Pasadena, California*

FRONTIER is a computer program that functions as a front end for any of a variety of other software of both the artificial intelligence (AI) and conventional data-processing types. As used here, "front end" signifies interface software needed for acquiring and preprocessing data and making the data available for analysis by the other software. FRONTIER is reusable in that it can be rapidly tailored to any such other software with minimum effort. Each component of FRONTIER is programmable and is executed in an em-

bedded virtual machine. Each component can be reconfigured during execution. The virtual-machine implementation making FRONTIER independent of the type of computing hardware on which it is executed.

The top-level elements of FRONTIER are written in the C language for real-time performance. However, configuration-setup, preprocessing, conversion, advanced analysis (AI) algorithms and noise-source definitions are written in a virtual language that can be downloaded to each of its components while they are

running to provide hot swaps of software. FRONTIER is composed of one non-reusable component and seven reusable ones. The non-reusable component is the one that interfaces to the external world to acquire the data.

*This program was written by Mark James of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42087.*



### **Nanocomposite Photoelectrochemical Cells**

**Efficiencies greater than those of state-of-the-art cells are predicted.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Improved, solid-state photoelectrochemical cells for converting solar radiation to electricity have been proposed. (In general, photoelectrochemical cells convert incident light to electricity through electrochemical reactions.) It is predicted that in comparison with state-of-the-art photoelectrochemical cells, these cells will be found to operate with greater solar-to-electric energy-conversion efficiencies.

The proposed cells could be fabricated by layering nanocomposites of active particles with organic binders on flexible polymer substrates. Each cell would contain a dye-sensitized semiconductor electrode, a proton-conducting solid electrolyte, and a solid-state pro-

ton-intercalation counter electrode. By designing the cells to rely on protons as the charge carriers, it should be possible to enable the cells to sustain rates of transport and concentrations of charge carriers greater than those of state-of-the-art photoelectrochemical cells designed to rely on hole conduction and organic semiconductors. The proposed cell configuration is expected to minimize the incidence of recombination of holes and electrons, thereby minimizing the energy losses associated with them and thereby, further, contributing to greater energy-conversion efficiencies.

*This work was done by Sri R. Narayan, Andrew Kindler, and Jay F. Whitacre of Cal-*

*tech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to NPO-40539, volume and number of this NASA Tech Briefs issue, and the page number.*

### **Ultracapacitor-Powered Cordless Drill**

**Whereas charging of batteries usually take hours, ultracapacitors can be charged in seconds.**

*John H. Glenn Research Center, Cleveland, Ohio*

The figure depicts a portable, hand-held power drill with its attached power-supply unit, in which ultracapacitors, rather than batteries, are used to store energy. This ultracapacitor-powered drill is a product of continuing efforts to develop the technological discipline known as hybrid power management (HPM), which is oriented toward integration of diverse electric energy-generating, energy-storing, and energy-consuming devices in optimal configurations.

Instances of HPM were reported in several prior *NASA Tech Briefs* articles, though not explicitly labeled as HPM except in the most recent such article, which was "Hybrid Power Management" (LEW-17520-1), Vol. 29, No. 12 (December 2005), page 35. To recapitulate from that article: The use of ultracapacitors as energy-storage devices lies at the heart of HPM. An ultracapacitor is an electrochemical energy-storage device, but unlike in a conventional rechargeable electrochemical cell or battery, chemical reactions do not take place during oper-

ation. Instead, energy is stored electrostatically at an electrode/electrolyte interface. The capacitance per unit volume of an ultracapacitor is much greater than that of a conventional capacitor because its electrodes have much greater surface area per unit volume and the separation between the electrodes is much smaller.

HPM offers many advantages over the conventional power-management approach in which batteries are used to store energy. To place the present development in context, it is necessary to reiterate these advantages from the cited previous article:

- Power-control circuits for ultracapacitors can be simpler than those for batteries for two reasons: (1) Because of the absence of chemical reactions, charge and discharge currents can be greater than those in batteries, limited only by the electrical resistances of conductors; and (2) Whereas the charge level of a battery depends on voltage, temperature, age, and load condition, the charge level of an ultracapacitor, like that of

a conventional capacitor, depends only on voltage.

- Whereas a typical battery can be charged and discharged about 300 times, an ultracapacitor can be charged and discharged more than a million times. The longer lifetimes of ultracapacitors contribute to reliability.
- The longer lifetimes of ultracapacitors greatly reduce life-of-system costs, including the indirect costs of maintenance and downtime.
- The longer lifetimes of ultracapacitors reduce adverse environmental effects, inasmuch as it will probably never be necessary to replace and dispose of ultracapacitors in most applications, whereas batteries must be replaced frequently.
- Disposal problems and the associated contributions to life-of-system costs can be reduced because the chemical constituents of ultracapacitors are less toxic and less environmentally harmful than are those of batteries. Indeed, ultracapacitors are somewhat recyclable.



The **Power Pack** attached to the bottom of the handle of the power drill utilizes ultracapacitors, rather than batteries, to store energy.

- Excellent low-temperature performance makes ultracapacitors suitable for storing energy in applications at temperatures too low for batteries.
- The consistent performance of ultracapacitors over time enables reliable operation not possible with batteries.
- Unlike batteries, ultracapacitors can be safely left completely discharged for indefinitely long times.
- Whereas the charge-discharge efficiency in conventional power management using rechargeable batteries is typically about 50 percent, the charge-discharge efficiency in HPM typically exceeds 90 percent.

For the cordless drill, a dedicated charger is used to fully realize the advantages of the ultracapacitors as energy-storage devices. Because of the non-critical nature of charging and dis-

charging of ultracapacitors, this charger is less complex and less costly than would be a battery charger for the same power drill. More spectacularly, taking advantage of the unique charging characteristics of ultracapacitors, this charger can make the ultracapacitor-powered cordless drill ready for operation in seconds, in contradistinction to the several hours needed to recharge batteries.

*This work was done by Dennis J. Eichenberg of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18116-1.*



## Cumulative Timers for Microprocessors

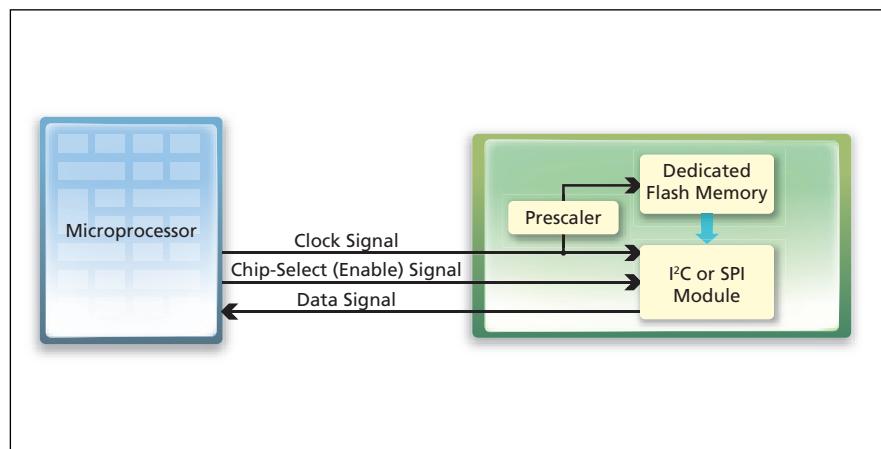
**Accumulated operating times and serial numbers would be displayed.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

It has been proposed to equip future microprocessors with electronic cumulative timers, for essentially the same reasons for which land vehicles are equipped with odometers (total-distance-traveled meters) and aircraft are equipped with Hobbs meters (total-engine-operating-time meters). Heretofore, there has been no way to determine the amount of use to which a microprocessor (or a product containing a microprocessor) has been subjected. The proposed timers would count all microprocessor clock cycles and could only be read by means of microprocessor instructions but, like odometers and Hobbs meters, could never be reset to zero without physically damaging the chip.

A timer according to the proposal could be either an external device connected to a microprocessor or embedded within the microprocessor. The external implementation could be retrofit to a pre-existing microprocessor. In the external implementation (see figure), the timer would include a prescaler; an inter-integrated-circuit (I<sup>2</sup>C) or a serial peripheral interface (SPI) module; and a flash random-access memory (RAM) that would store a unique serial number and a prescaler-reduced count of clock cycles, both of which could be read over a one- or two-wire bus.

The serial number stored in the flash RAM would serve as the serial number



A **Cumulative Timer** could be added to a microprocessor as an electrically connected external unit. Alternatively, it could be incorporated as an integral part of the microprocessor.

of the microprocessor and of any equipment containing the microprocessor, for purposes of registering any warranty of the equipment and verifying the authenticity of the equipment. On a display generated by the microprocessor, the user could compare the electronically stored serial number with the serial number printed on a label affixed to the equipment and the serial number on the warranty registration and could read the accumulated operating time. Periodically, during normal operation, the microprocessor would attempt to interrogate the flash memory

and would turn itself off if it were unable to read its proper serial number. Upon each such interrogation, the count stored in the flash memory would be incremented.

The internal implementation would function similarly to the external implementation, except that the serial number and the prescaler-reduced count of clock cycles would be stored in either (1) part of the flash RAM used by the rest of the microprocessor or (2) a separate flash RAM dedicated to the timer. It would be necessary to design the microprocessor hardware

and software so that there would be no way to decrement the count or otherwise exert external control over the timer flash RAM.

*This work was done by John O. Battle of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a*

*TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to NPO-43599, volume and number of this NASA Tech Briefs issue, and the page number.*





## Photocatalytic/Magnetic Composite Particles

**Magnetic agitation enhances effectiveness.**

*Lyndon B. Johnson Space Center, Houston, Texas*

Photocatalytic/magnetic composite particles have been invented as improved means of exploiting established methods of photocatalysis for removal of chemical and biological pollutants from air and water. The photocatalytic components of the composite particles

are formulated for high levels of photocatalytic activity, while the magnetic components make it possible to control the movements of the particles through the application of magnetic fields. The combination of photocatalytic and magnetic properties can be exploited in designing improved air- and water-treatment reactors.

A typical composite particle according to the invention (see Figure 1) includes a magnetic substrate or core particle having a size of the order of 100  $\mu\text{m}$ , a layer to protect the core against chemical attack, and an outer coat of nano-sized photocatalyst particles on the protective layer. In an application in which the protective layer is not needed, it can

be omitted and the photocatalyst particles coated directly onto the core. Another option is to make the core of a nonmagnetic material and to coat it with nano-sized photocatalyst and magnetic particles.

As used here, “nano-sized” refers to sizes in the range from a few nanometers to about 100 nanometers. The reason for choosing this size range is simply that experience has shown that nano-sized photocatalyst particles are more photocatalytically active than are micron- and larger-sized photocatalyst particles.

The magnetic core (or, optionally, the nano-sized magnetic particles) can be made of any of a variety of suitable magnetic materials — for example,  $\text{Fe}_3\text{O}_4$ ,

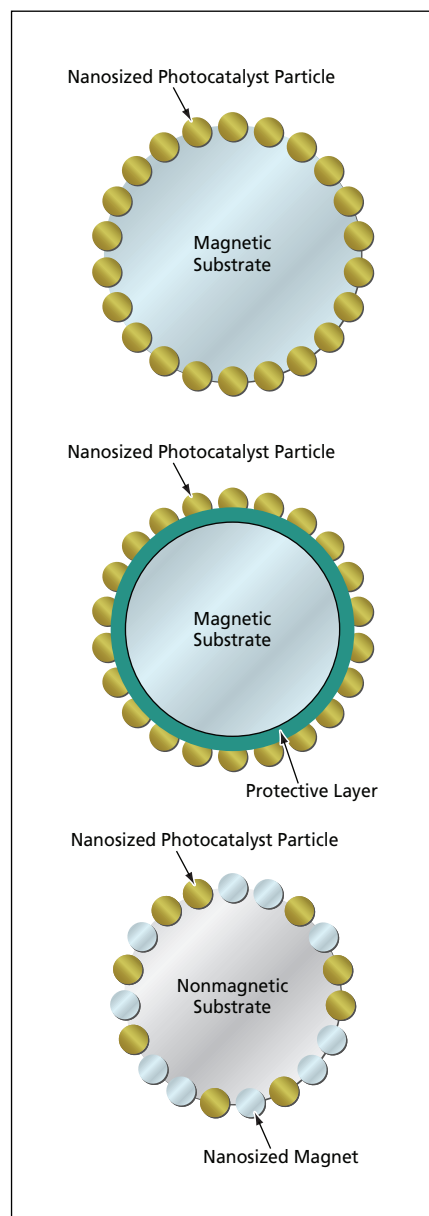


Figure 1. **Photocatalytic/Magnetic Composite Particles** according to the invention can be made in different forms.

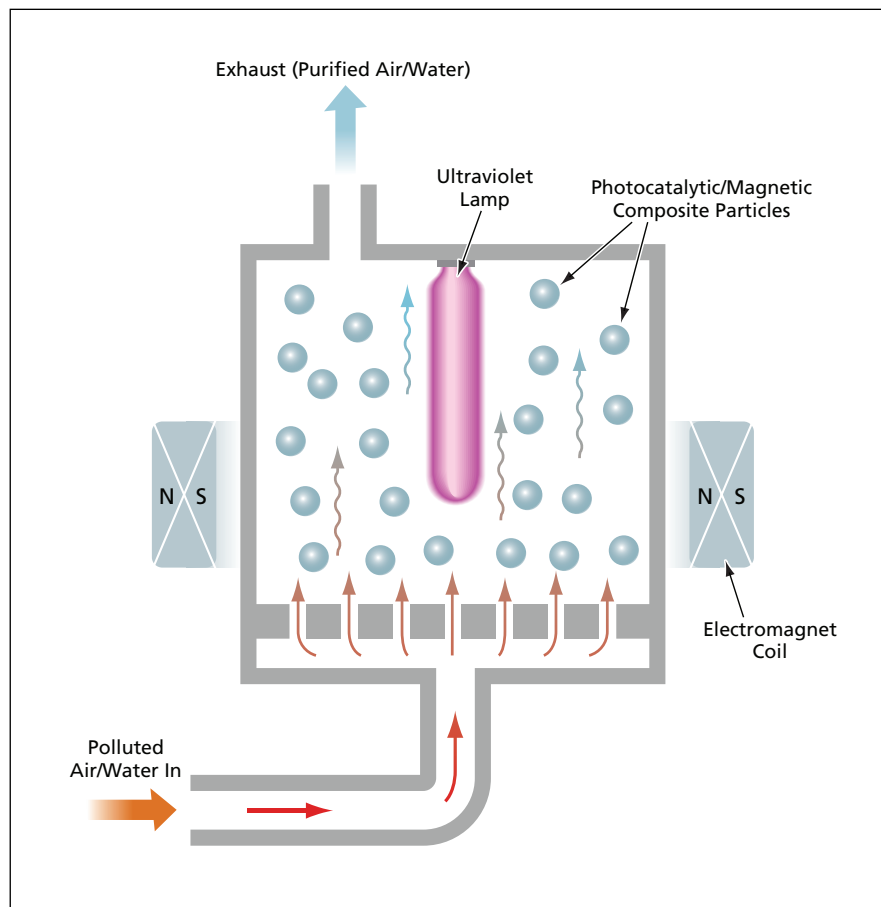


Figure 2. A **Fluidized Bed** containing photocatalytic/magnetic composite particles is illuminated by ultraviolet light. The bed is agitated by the flow of polluted air to be treated and by an alternating magnetic field.

BaO(Fe<sub>2</sub>O<sub>3</sub>)<sub>6</sub>, SrO(Fe<sub>2</sub>O<sub>3</sub>)<sub>6</sub>, or AlNiCo. The protective layer can be a polymer or a ceramic — for example, poly(tetraethylfluoroethylene) or poly(methyl methacrylate) or silica. The photocatalyst can be TiO<sub>2</sub>, ZnO, or Fe<sub>2</sub>O<sub>3</sub>. Nano-sized photocatalyst particles can be coated onto the larger core particles by various techniques, e.g., a dry coating machine, wherein a mixture of the two types of particles is forced to pass through a narrow clearance under high stress.

A representative reactor for treatment of air by use of photocatalytic/magnetic composite particles (see Figure 2) includes a fluidized bed loaded with the particles. An ultraviolet lamp provides the excitatory photons needed for photocatalysis. An electromagnet coil generates

a magnetic field to control the movement of the composite particles.

In operation, polluted air or water enters at the bottom and flows upward through the fluidized bed. The polluted fluid agitates, and mixes with, the composite particles in the bed. Additional agitation is provided by an alternating magnetic field generated by supplying alternating current to the electromagnet coil. The agitation enhances the fluidization, and is almost entirely responsible for fluidization when the flow is not rapid enough to fluidize the particles sufficiently. The agitation promotes the exposure of the photocatalyst particles to ultraviolet light from the lamp and increases the rate of generation of hydroxyl radicals, which react with the pollutants. The

exhaust flowing from the top of the reactor consists of purified fluid.

*This work was done by Chang-Yu Wu, Yogi Goswami, Charles Garretson, Jean Andino, and David Mazyck of the University of Florida for Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*University of Florida, Environmental Engineering  
Black Hall  
Gainesville, FL 32611*

*Refer to MSC-23829, volume and number of this NASA Tech Briefs issue, and the page number.*





## Separation and Sealing of a Sample Container Using Brazing

This process is an alternative to a prior explosive welding process.

NASA's Jet Propulsion Laboratory, Pasadena, California

A special double-wall container and a process for utilizing the container are being developed to enable (1) acquisition of a sample of material in a "dirty" environment that may include a biological and/or chemical hazard; (2) sealing a lid onto the inner part of the container to hermetically enclose the sample; (3) separating the resulting hermetic container from the dirty environment; and (4) bringing that hermetic container, without any biological or chemical contamination of its outer surface, into a clean environment. The process is denoted "S<sup>3</sup>B" (separation, seaming, and sealing using brazing) because sealing of the sample into the hermetic container, separating the container from the dirty environment, and bringing the container with a clean outer surface into the clean environment are all accomplished simultaneously with a brazing operation. This container and process were conceived as a superior alternative to the double-wall container and process described in "Explosion Welding for Hermetic Containerization" (NPO-20868), NASA Tech Briefs, Vol. 27, No. 8 (August 2003), page 46. As in the previously reported case, the present container and process were originally intended to be used to return samples from Mars to Earth, but could also be used on Earth to store and transport material samples acquired in environments that contain biological and/or chemical hazards.

Figure 1 depicts the configuration, prior to the S<sup>3</sup>B process, of the double-wall container and an interface assembly that includes a structure that holds the lid and serves as a barrier between the clean and dirty environments. The upper end of the container is sized and shaped to mate with the lid. For the S<sup>3</sup>B process, the outer wall of the double-wall container includes, near its upper end, integral portions in the form of three rings of a brazing material that melts at a temperature well below the melting temperature of the rest of the container. There is also a similar ring of brazing material on the upper surface of a

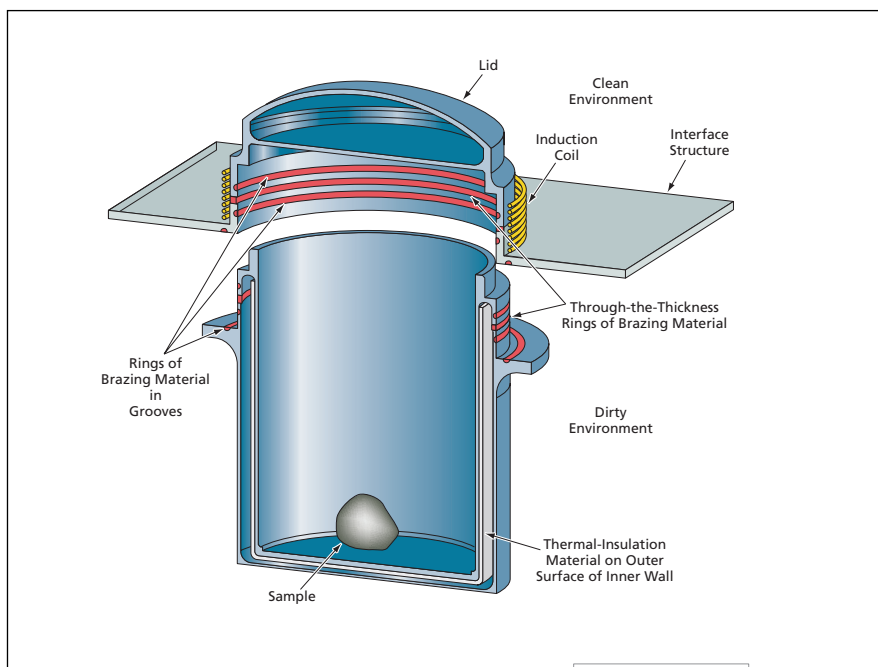


Figure 1. Before the S<sup>3</sup>B Process, the double-wall container and the sample inside it are in the dirty environment.

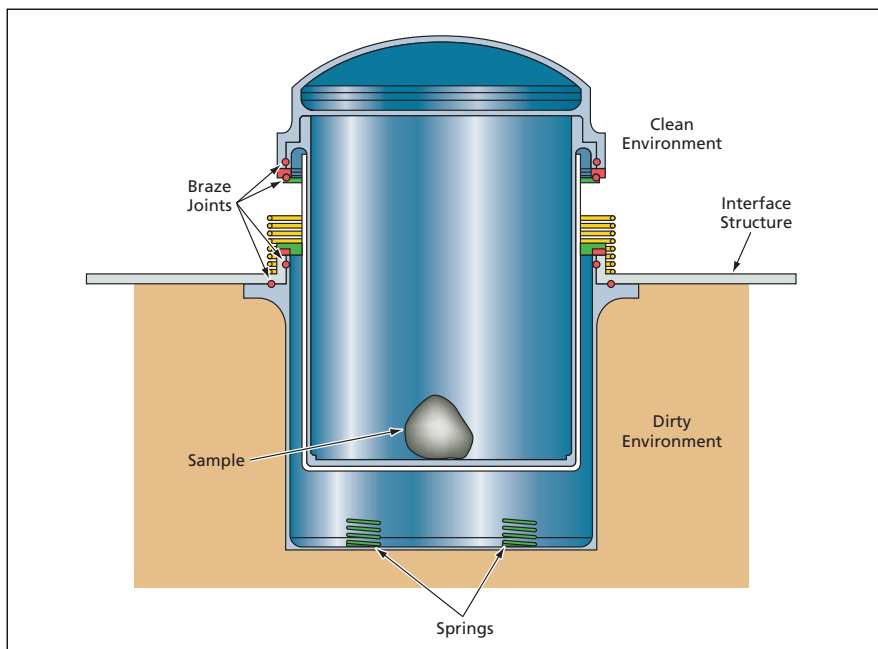


Figure 2. After the S<sup>3</sup>B Process, the sample is hermetically sealed into a container newly created from the inner wall of the double-wall container and the lid, and the newly created container resides in the clean environment.

flange that is part of, and near the upper end of, the outer wall. Inside the lid and on the structure that holds the lid are similar rings of brazing material positioned to mate with those on the double-wall container. The middle ring of brazing material on the cylindrical portion of the outer wall occupies the full thickness of the wall; similarly, the mating middle ring of brazing material in the cylindrical portion of the lid occupies the full thickness of that part of the lid. On the clean side, an induction-heating coil surrounds the lid. At the bottom end of the double-wall container, between the inner and outer walls, are springs poised to push the inner portion of the container lengthwise out of the outer portion.

Immediately before starting the S<sup>3</sup>B process, a mechanism pushes the double-wall container into mating with the

lid. The S<sup>3</sup>B process is started by applying power to the induction-heating coil to melt the rings of brazing material, thereby causing the following events to occur simultaneously:

- The outer wall of the double-wall container becomes brazed to the interface structure, thereby ensuring maintenance of the separation between the clean and dirty environments.
- The inner wall of the double-wall container becomes brazed to the lid, thereby creating an inner container and hermetically sealing the sample into it.
- Once the through-the-thickness rings of brazing material melt, there is nothing left to hold the inner container to the outer container or to hold the lid to the interface structure. Consequently, the springs push the newly created hermetic container away from the outer container/interface struc-

ture, into the clean environment (see Figure 2).

The brazing material is chosen to have a sufficiently high melting temperature (typically >500 °C) so that the brazing process sterilizes the outer surface of the lid/wall seam region of the newly created hermetic container. The outer surface of the inner container is covered with a layer of thermal-insulation material to prevent heat damage of the sample during brazing. Alternatively, in an application in which there is no concern about biological contamination, it could be feasible to substitute a lower-melting-temperature solder for the brazing material.

*This work was done by Yoseph Bar-Cohen, Tommaso P. Rivellini, James E. Wincentzen, and Robert Gershman of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-41024*



## Automated Aerial Refueling Hitches a Ride on AFF

Data from flight tests will be used in designing an automated refueling system.

*Dryden Flight Research Center, Edwards, California*

The recent introduction of uninhabited aerial vehicles [UAVs (basically, remotely piloted or autonomous aircraft)] has spawned new developments in autonomous operation and posed new challenges. Automated aerial refueling (AAR) is a capability that will enable UAVs to travel greater distances and loiter longer over targets.

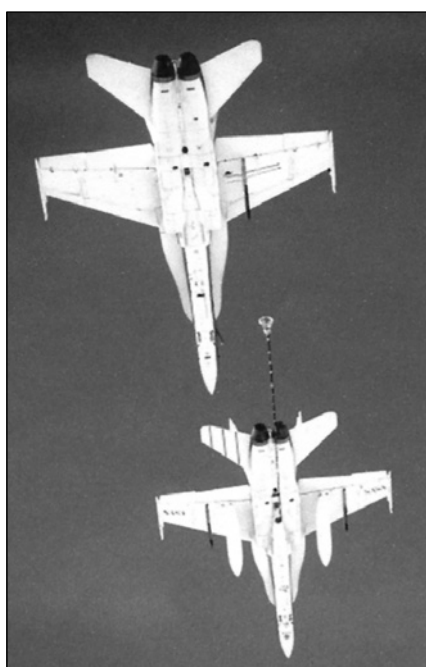


Figure 1. The Two F/A-18A Airplanes — one configured as a tanker, the other trailing it in the role of a receiver — were photographed from below flying in formation.

NASA Dryden Flight Research Center, in cooperation with the Defense Advanced Research Projects Agency (DARPA), the Naval Air Systems Command (NAVAIR), the Naval Air Force Pacific Fleet, and the Air Force Research Laboratory, rapidly conceived and accomplished an AAR flight research project focused on collecting a unique, high-quality database on the dynamics of the hose and drogue of an aerial refueling system. This flight-derived database would be used to validate mathematical models of the dynamics in support of design and analysis of AAR systems for future UAVs. The project involved the use of two Dryden F/A-18 airplanes and an S-3 hose-drogue refueling store on loan from the Navy (see Figure 1). In this year-long project, which was started on October 1, 2002, 583 research maneuvers were completed during 23 flights.

In the first phase of the project, the aerial refueling store (ARS) was instrumented and fully integrated with one of the F/A-18A airplanes — an integration that had not previously been accomplished. After conducting envelope-expansion flights in December 2002 for this F/A-18A airplane to carry and operate the ARS, the project team focused on outfitting both F/A-18A airplanes with a pair of video cameras to record the movement of the hose-and-drogue

system. Building on the heritage of technological developments of the Autonomous Formation Flight (AFF) program, the dynamics of the hose and drogue were investigated at altitudes between 7,500 and 30,000 feet (between 2.3 and 9.1 km), and indicated airspeeds ranging from 195 to 300 knots (100 to 154 m/s). The effects of flight conditions, the weight of the hose, the weight of the tanker (the airplane carrying the ARS), and the approach velocity of the receiver (the other airplane, playing the role of an airplane to be refueled) on the response of the hose and drogue were explored in increments. A Global Positioning System (GPS)-based relative-positioning capability developed in the AFF program was used to guide the receiver into the proper position behind the tanker. Post-flight processing of the video images yielded data on the position and velocity of the hose/drogue system.

The free-stream position of the drogue (see Figure 2), the drag upon the drogue, and the effects of turbulence upon the drogue were investigated. Also investigated were the damping characteristics of the hose and the area of influence — the region around the drogue wherein there is a discernable effect on the drogue.

Similarly to the research of the AFF program, the research of the AAR program included exploration of many avenues, including video tracking and calibration methods, and flight-test and piloting techniques. The unique configuration of the airplanes enabled the first-ever in-flight thrust measurement of drag on the hose and drogue. It also enabled synchronization of the measurement of the hose and drogue position relative to the tanker and receiver with both GPS measurements and data acquired aboard both airplanes. Preliminary analysis of the video-derived data is complete.

*This work was done by Jennifer L. Hansen, James E. Murray, Glenn Bever, Norma V. Campos, and Gerard Schkolnik of Dryden Flight Research Center. Further information is contained in a TSP (see page 1).  
DRC-04-13*

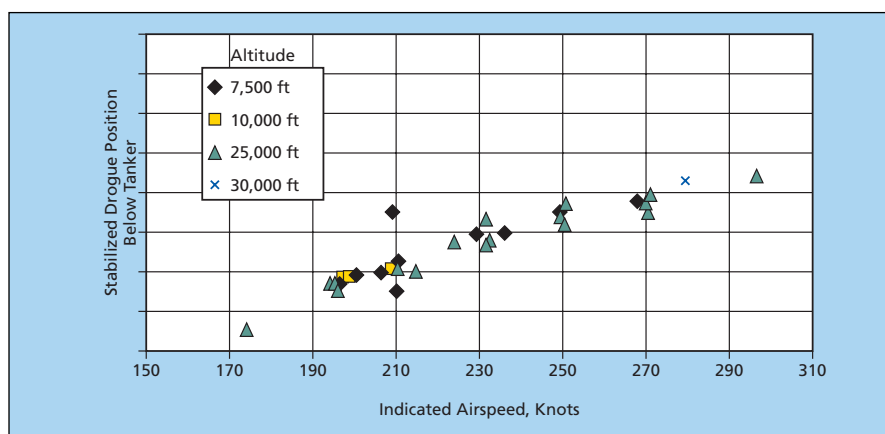


Figure 2. The Relative Vertical Position of the drogue was measured as a function of airspeed at four different altitudes.

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## ✿ Cobra Probes Containing Replaceable Thermocouples

*John H. Glenn Research Center, Cleveland, Ohio*

A modification of the basic design of cobra probes provides for relatively easy replacement of broken thermocouples. [Cobra probes are standard tube-type pressure probes that may also contain thermocouples and that are routinely used in wind tunnels and aeronautical hardware. They are so named because in side views, they resemble a cobra poised

to attack.] Heretofore, there has been no easy way to replace a broken thermocouple in a cobra probe: instead, it has been necessary to break the probe apart and then rebuild it, typically at a cost between \$2,000 and \$4,000 (2004 prices). The modified design makes it possible to replace the thermocouple, in minimal time and at relatively low cost, by insert-

ing new thermocouple wire in a tube.

*This work was done by John Jones and Adam Redding of Glenn Research Center.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17832-1.*



## High-Speed Noninvasive Eye-Tracking System

**This system operates at a frame rate of several kilohertz.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The figure schematically depicts a system of electronic hardware and software that noninvasively tracks the direction of a person's gaze in real time. Like prior commercial noninvasive eye-tracking systems, this system is based on (1) illumination of an eye by a low-power infrared light-emitting diode (LED); (2) acquisition of video images of the pupil, iris, and cornea in the reflected infrared light; (3) digitization of the images; and (4) processing the digital image data to determine the direction of gaze from the centroids of the pupil and cornea in the images. Relative to the prior commercial systems, the present system operates at much higher speed and thereby offers enhanced capability for applications that involve human-computer interactions, including typing and computer command and control by handicapped individuals,

and eye-based diagnosis of physiological disorders that affect gaze responses.

Most of the prior commercial noninvasive eye-tracking systems rely on standard video cameras, which operate at frame rates of about 30 Hz. In a typical system, the video-data stream is processed either in the central processing unit of a host computer or in a digital signal processor on a frame-grabber board. Such a system is limited to slow, full-frame operation in which the burden of processing the full-frame image data is placed on the host computer.

In the present system, most control functions and processing of image data are performed by firmware on an on-board field-programmable gate array (FPGA). This aspect of the design relieves the host computer of much of the

burden of transferring full-image data via the host bus (which is typically a slow operation) or the need to process the full image data after transfer to the host PC. The firmware for the FPGA is relatively easily extendable to the design of a compact application-specific integrated circuit that could be mass-produced. It is envisioned that with further development, the architecture of this system could progress to that of an affordable, portable, stand-alone computer-peripheral unit similar to an optical mouse.

Another important aspect of the design is an advanced control scheme for a charge-coupled device (CCD) image detector. The scheme provides for readout from a small region of interest (ROI), or subwindow, of the full image. Because the ROI contains significantly far fewer pixels than does the full image, one can achieve a high frame rate by reading out the ROI (but not the rest of the image) repeatedly. Inasmuch as the image features of interest (the cornea and pupil) typically occupy a small part of the camera frame, this ROI capability enables determination of the direction of gaze at a high rate. At present, commercial CCD cameras are not well suited to implementation of this scheme, and a custom camera is used instead. This camera, which has an active image area of 658 by 496 pixels, is capable of readout from an 8-by-8-pixel ROI at a rate of 6 kHz.

*This work was done by Ashit Talukder, Clayton La Baw, John Michael-Morookian, Steve Monacos, and Orin Serviss of Caltech for NASA's Jet Propulsion Laboratory.*

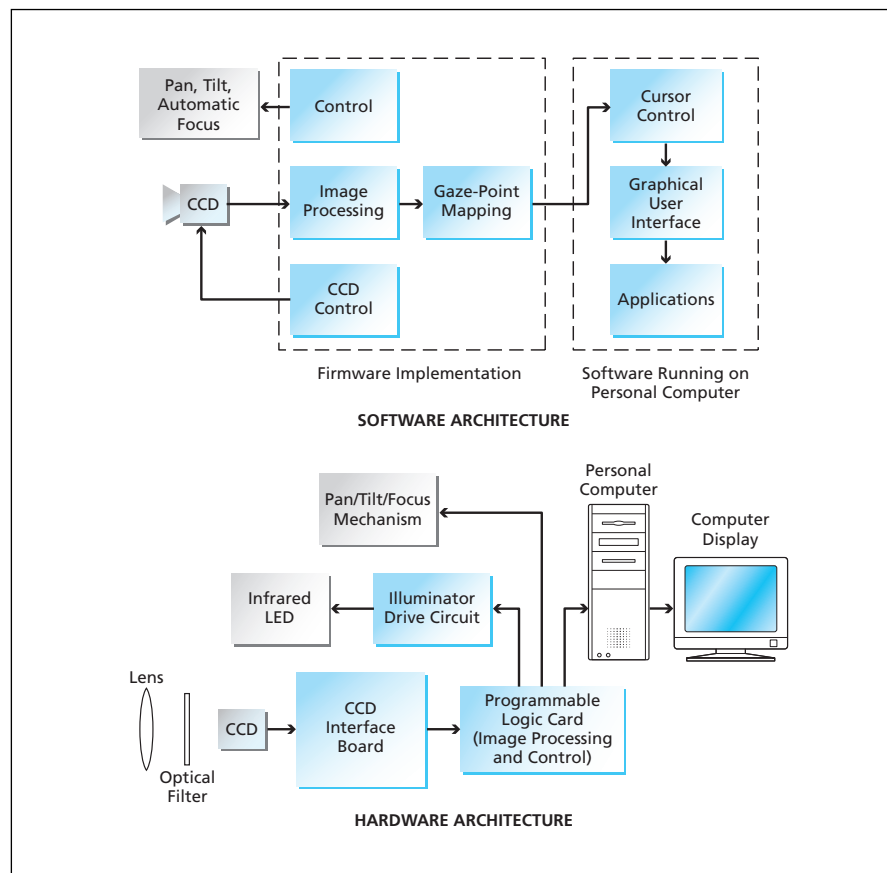
*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*Innovative Technology Assets Management  
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*Refer to NPO-30700, volume and number of this NASA Tech Briefs issue, and the page number.*



The **Software and Hardware Architectures** of this noninvasive eye-tracking system differ significantly from those of prior such systems in ways that enable this system to operate at much higher speeds.

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## Detergent-Specific Membrane Protein Crystallization Screens

*Marshall Space Flight Center, Alabama*

A suite of reagents has been developed for three-dimensional crystallization of integral membranes present in solution as protein-detergent complexes (PDCs). The compositions of these reagents have been determined in part by proximity to the phase boundaries (lower consolute boundaries) of the detergents present in the

PDCs. The acquisition of some of the requisite phase-boundary data and the preliminary design of several of the detergent-specific screens was supported by a NASA contract. At the time of expiration of the contract, a partial set of preliminary screens had been developed. This work has since been extended under non-NASA sponsorship,

leading to near completion of a set of 20 to 30 different and unique detergent-specific 96-condition screens.

*This work was done by Michael Wiener of the University of Virginia for Marshall Space Flight Center. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at [sammy.a.nabors@nasa.gov](mailto:sammy.a.nabors@nasa.gov). Refer to MFS-32436-1.*



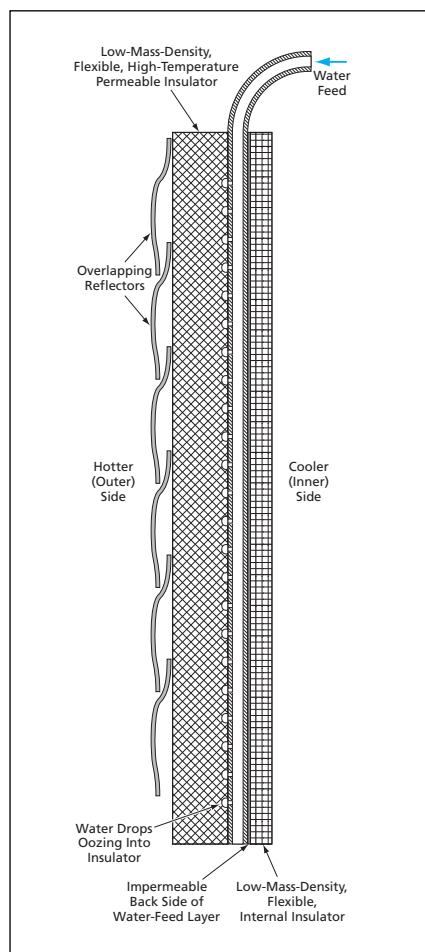
## Evaporation-Cooled Protective Suits for Firefighters

**In comparison with suits now in use, these could protect for longer times.**

*Langley Research Center, Hampton, Virginia*

Suits cooled by evaporation of water have been proposed as improved means of temporary protection against high temperatures near fires. When air temperature exceeds 600 °F (316 °C) or in the presence of radiative heating from nearby sources at temperatures of 1,200 °F (649 °C) or more, outer suits now used by firefighters afford protection for only a few seconds. The proposed suits would exploit the high latent heat of vaporization of water to satisfy a need to protect against higher air temperatures and against radiant heating for significantly longer times. These suits would be fabricated and operated in conjunction with breathing and cooling systems like those with which firefighting suits are now equipped.

A protective suit according to the proposal would include a water-storage and -distribution system that would cause the suit to “sweat” all over as needed. The quantity of water carried (typically a few liters) could be selected according to the expected task. If the water were carried in a slightly pressurized tank, there would be no need for a pump. The water-distribution system would include bimetallic-actuated valves that would regulate rates of flow according to the local temperatures in the suit. For example, it has been estimated that releasing water at a rate of 1 milliliter per second would be sufficient to prevent the surface temperature of the suit from exceeding 140 °F (60 °C) at an air temperature of 1,000 °F (538 °C), and a 2-liter supply of water would be more



**Shinglelike Outer Reflectors** would protect against radiative heating. Evaporation of water from the inner surface of a permeable insulating layer would keep the interior temperature much lower than the ambient air temperature.

than enough to provide this protection for half an hour. The adjustability of flow rates would also make it possible to protect against radiative heating for times longer than were previously possible.

For even better protection against both conductive and radiative heating, a suit according to the present proposal could include both a highly reflective outer layer as well as an evaporative-cooling sublayer system. Whereas the outer layers of some protective suits now in use have reflectivities of about 0.90, the proposal calls for a reflectivity of about 0.97. In one version, shown in the figure, the outer layer would consist of overlapping shinglelike reflectors (see figure), possibly made of thin copper plates coated with gold. The shingles would be individually attached to the suit so that they could slide over each other and motion would not be restricted. The water would be injected into, and would evaporate from the inner surface of a thick, permeable insulating layer, which is shielded by the reflective shingles. The shingles would be allowed to get very hot, but the wet sub-layer would remain much cooler, and water would be used up at a lower rate than would be the case if no reflective shingles were used and water were allowed to evaporate directly from a hot outer surface.

*This work was done by Leonard Murray Weinstein of Langley Research Center. For further information, contact the Langley Innovative Partnerships Office at (757) 864-8881. LAR-16245-1*

## Plasmonic Antenna Coupling for QWIPs

**Plasmonic antennas would be potentially superior alternatives to surface corrugations.**

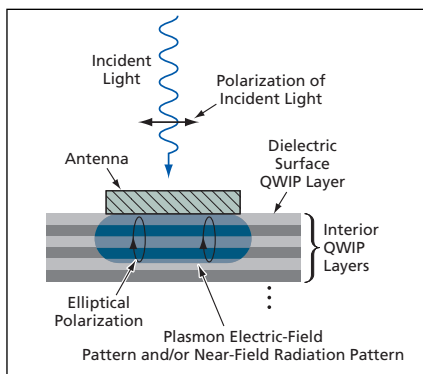
*NASA's Jet Propulsion Laboratory, Pasadena, California*

In a proposed scheme for coupling light into a quantum-well infrared photodetector (QWIP), an antenna or an array of antennas made of a suitable metal would be fabricated on the face of what would otherwise be a standard QWIP (see figure). This

or any such coupling scheme is required to effect polarization conversion: Light incident perpendicularly to the face is necessarily polarized in the plane of the face, whereas, as a matter of fundamental electrodynamics and related quantum selec-

tion rules, light must have a non-zero component of perpendicular polarization in order to be absorbed in the photodetection process. In a prior coupling scheme, gratings in the form of surface corrugations diffract normally incident light to oblique an-





A **Surface Plasmon** with elliptical polarization would form under the antenna. The perpendicular component of the elliptical polarization would enable absorption of the incident light.

gles, thereby imparting some perpendicular polarization. Unfortunately, the corrugation-fabrication process increases the overall nonuniformity of a large QWIP array. The proposed scheme is an alternative to the use of surface corrugations.

For a given QWIP, the metal and the size and shape of the antenna would be chosen so that the combination of the antenna and the adjacent surface dielectric layer of the QWIP would support surface plasmon states at wavelengths of interest. The interface between a dielectric and a metal can support a surface electromagnetic wave if the permittivity of the metal, expressed as a complex number, has a negative real component. The distribution of amplitude in a plasmon peaks at the metal/dielectric interface and decays exponentially with distance from the interface into the metal or the dielectric.

In cases relevant to the proposal, the polarization states of the electric field are elliptical, characterized by major axes parallel to the interface on the metal side and perpendicular to the interface in the dielectric side. The contribution of the surface-plasmon effect to perpendicular polarization would be

augmented by the contribution of strong perpendicular-polarization components of the near field of the antenna. Presumably, designs could also be optimized to obtain resonant or broadband antenna structures to maximize coupling of light from free space into perpendicularly polarized plasmon modes.

*This work was done by John Hong of Caltech for NASA's Jet Propulsion Laboratory.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*Innovative Technology Assets Management*

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*Refer to NPO-43681, volume and number of this NASA Tech Briefs issue, and the page number.*

## **Electronic Tongue Containing Redox and Conductivity Sensors**

**Progress has been made toward long-lived sensors for monitoring water quality.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Electronic tongue 2 (E-tongue 2) represents the second generation of the apparatus described in "Electronic Tongue for Quantitation of Contaminants in Water" (NPO-30601), *NASA Tech Briefs*, Vol. 28, No. 2 (February 2004), page 31. To recapitulate: The previously reported apparatus, now retrospectively denoted E-tongue 1, is an assembly of sensors for measuring concentrations of metal ions and possibly other contaminants in water. Potential uses for electronic tongues include monitoring the chemical quality of water in a variety of natural, industrial, and laboratory settings, and detecting micro-organisms indirectly by measuring microbially influenced corrosion.

E-tongue 2 includes a heater, a temperature sensor, an oxidation/reduction (redox) sensor pair, an electrical sensor, an array of eight galvanic cells, and eight ion-specific electrodes. These devices are formed in a substantially planar configuration on an alumina substrate 1 mm thick and 1.3 in. (3.3 cm) in diameter (see Figure 1). The fabrication process includes screen printing of the components of the aforementioned devices on the front side of the substrate, laser drilling of via holes for electrical contacts with wires

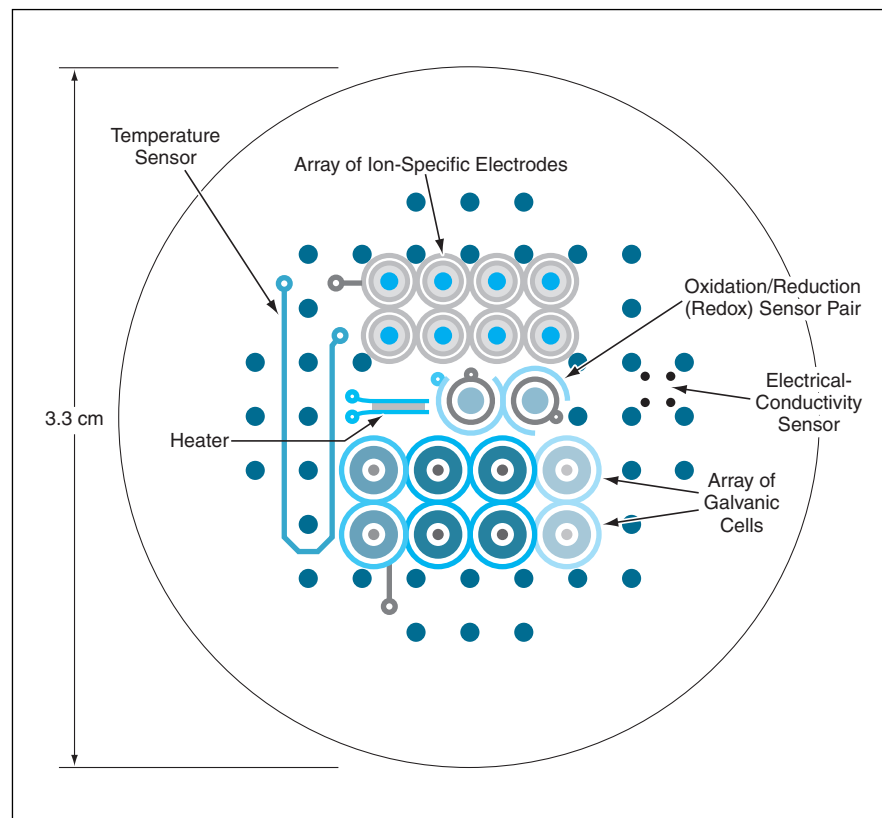


Figure 1. The **Layout of E-Tongue 2** is nearly identical to the layout of E-tongue 1, depicted in an earlier *NASA Tech Briefs* article.



screen-printed on the back side of the substrate, rendering the vias conductive by drawing screen-print material through them using partial vacuum on one side, adding pins for connection to external circuitry, and firing the printed substrate in air at high temperature.

An important aspect of the planar configuration is that the counter electrodes of all the cells in the array are integral parts of a grounded common conductor on the front surface of the substrate. The use of this common conductor helps to minimize the number of wires and pins and facilitates miniaturization of the array. The common conductor also serves as a ground plane that suppresses electric-field interference among the cells in the array.

The planarity of the array facilitates cleaning of the array by a number of techniques, including wiping, exposure to ultraviolet light, and electrolytic generation of hydrogen and oxygen. The planar configuration also facilitates the reservation of some cells and sensors as spares. The cleaning and sparing are intended to enable extension of the life of the E-tongue. Yet other advantages of the planar configuration are that it facilitates incorporation of the E-tongue into a flow-through cell and is amenable to microscopic observations.

The progression from E-tongue 1 to E-tongue 2 has involved improvements in design, operation, interpretation of

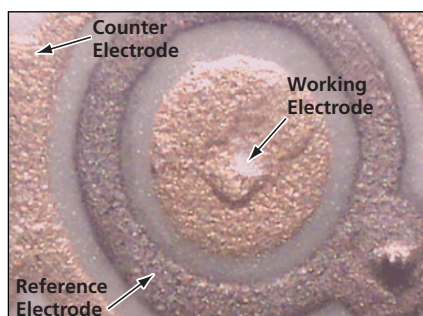


Figure 2. One of the Redox Sensors is shown here magnified. The working and counter electrodes are made of a platinum/gold alloy; the reference electrode is made of silver/palladium alloy. The inner diameter of the counter electrode is 2.75 mm.

sensor readings, and understanding of the underlying chemical and physical mechanisms, all directed toward development of large arrays of robust, long-lived sensors for monitoring water quality. There has been particular emphasis on the redox sensors, which are based on a traditional electrochemical cell used for making pH and other ionic-content measurements. Such a cell includes a working electrode, a reference electrode, and a counter electrode. However, whereas the electrodes in a traditional cell have a pencil-like configuration, the electrodes in each redox sensor of the E-tongue are planar and concentric (see Figure 2) and their counter electrodes are integral parts of the ground plane.

Excitation and readout circuitry has been designed and constructed specifically for use in operating the E-tongue. In operation, the currents flowing to and from the electrodes of the electrochemical cells and an adjacent electrical-conductivity sensor on the E-tongue are measured as the voltages applied to the electrodes are scanned through appropriate ranges, called detection windows. The measurement data are then processed and interpreted to detect and quantitate ions in solution. The detection windows are bounded by electrolytic generation of hydrogen at negative potentials and oxygen at positive potentials. In the case of the redox sensors of E-nose 2, the window is between  $-2$  and  $+1$  V.

*This work was done by Martin Buehler of Caltech for NASA's Jet Propulsion Laboratory.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## Improved Heat-Stress Algorithm

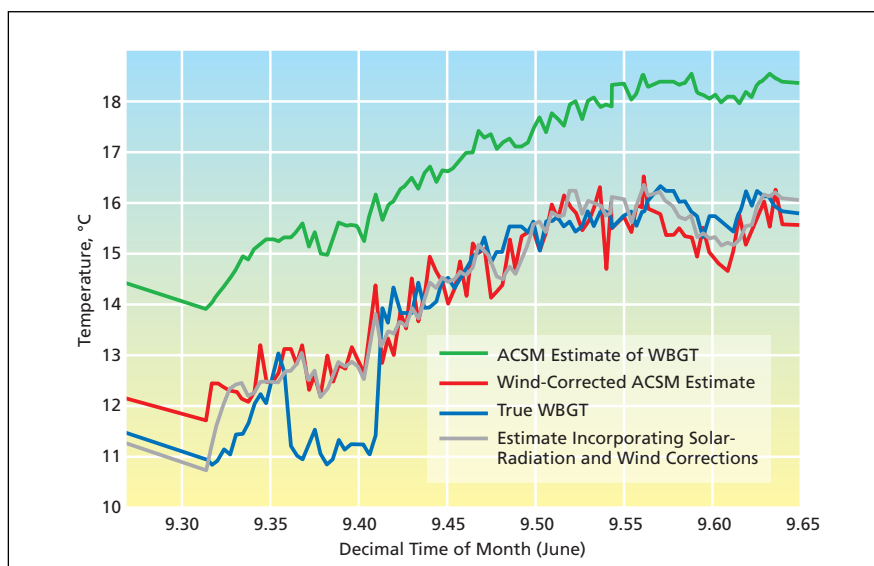
**Corrections for solar radiation and wind increase the accuracy of determining dangerous outdoor work environments.**

*Dryden Flight Research Center, Edwards, California*

NASA Dryden presents an improved and automated site-specific algorithm for heat-stress approximation using standard atmospheric measurements routinely obtained from the Edwards Air Force Base weather detachment. Heat stress, which is the net heat load a worker may be exposed to, is officially measured using a thermal-environment monitoring system to calculate the wet-bulb globe temperature (WBGT). This instrument uses three independent thermometers to measure wet-bulb, dry-bulb, and the black-globe temperatures. Two reasons for this project were limited access to the Dryden monitoring system and delays of the required manual issuances for heat-stress warnings.

Existing algorithms to estimate the WBGT are less applicable in dissimilar environments. The American College of Sports Medicine (ACSM) was the algorithm selected after being used extensively and successfully during the 2000 Summer Olympics in Sydney, Australia. The ACSM algorithm only uses dry ambient temperature and vapor pressure to estimate the WBGT and it assumes moderate solar radiation and low wind speeds. However, when applied to extreme environments such as the Southwest desert region, this algorithm produces less than acceptable WBGT values. This situation increases the likelihood of overlooking unsafe conditions for employees working outdoors.

Dryden provided corrections to the environmental assumptions of moderate solar radiation and low wind built into the algorithm. Desert environments, such as the high Mojave in Southern California, have both high solar radiation ( $1,000 \text{ W/m}^2$ ) and periods of significant winds during the summer afternoons in excess of 20 kn. When comparing the difference between the thermal environment monitor WBGT (actual) and the ACSM approximated WBGT against wind speed, it was found that a direct relationship existed with a positive slope (i.e., a large difference between the actual and estimated WBGT as the wind speed increases). A correction curve based on 40



ACSM Estimates of WBGT were brought closer to true WBGT values by applying corrections for wind and solar radiation.

days of comparisons was applied, and significant improvements to the WBGT approximations were observed. The daily difference between actual and calculated WBGT was reduced from approximately  $2.0^\circ$  to about  $0.5^\circ$  on the average.

Next, the moderate solar radiation assumption had to be addressed and was corrected by a similar process as that for the wind. Since at noon the solar radiation was the highest, the adjustments began there. The approximation algorithm produced reasonable values during the hours when the Sun was at its peak, but there were large overestimates in the morning and at night. To correct this, the differences between the actual and estimated WBGT were compared to solar radiation measurements. The results from this were again used to create another correction curve. The difference between actual and calculated WBGT was reduced from approximately  $2.0^\circ$  to about  $1.5^\circ$  on the average. Combining the two curves improved the estimation significantly better than  $0.5^\circ$  on the average for the 40 days.

By using these improvements, a more realistic WBGT estimation value can now be produced. A variety of advan-

tages come as a result of this. One of the most useful advantages is that a Web-based system can now be developed to automate and archive these calculations at a high update rate so that data are available everywhere for everyone. This Web automation system, in turn, will save meteorologists and safety personnel a considerable amount of time because they will no longer have to periodically record and archive WBGT measurements throughout the workday. Not only will the new algorithm help free up personnel but it will also make the thermal environment monitoring systems available to obtain site-specific WBGT data. This is extremely useful for researchers and other employees who are working on outdoor projects that are distant from the areas that the Web system monitors. Most importantly, the improved WBGT estimations will make outdoor work sites safer by reducing the likelihood of heat stress.

*This work was done by Edward H Teets, Jr., of Dryden Flight Research Center and Steven Frehn of Highland High School (Palmdale, CA). Further information is contained in a TSP (see page 1). DRC-05-01*

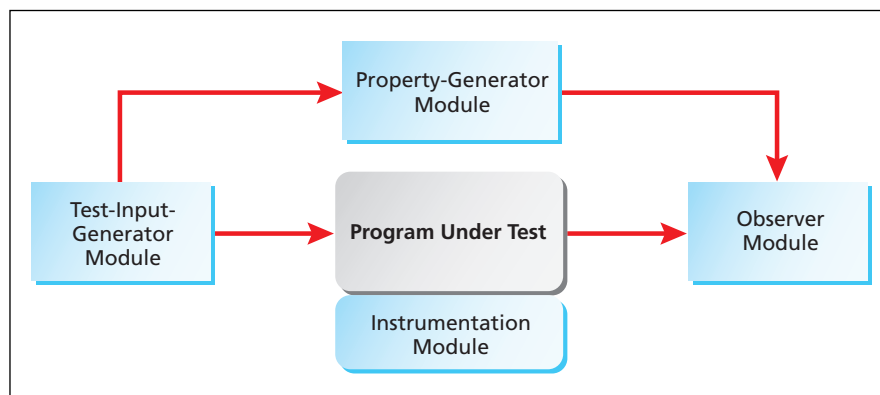
# ➤ A Method of Partly Automated Testing of Software

Principles of symbolic execution and temporal monitoring are exploited.

*Ames Research Center, Moffett Field, California*

A method of automated testing of software has been developed that provides an alternative to the conventional mostly manual approach for software testing. The method combines (1) automated generation of test cases on the basis of systematic exploration of the input domain of the software to be tested with (2) run-time analysis in which execution traces are monitored, verified against temporal-logic specifications, and analyzed by concurrency-error-detection algorithms. In this new method, the user only needs to provide the temporal logic specifications against which the software will be tested and the abstract description of the input domain.

For testing a given computer program, the method involves the software analog of a hardware test harness, consisting of four software modules: a test-input-generator module, a property-generator module, a program-instrumentation module, and an observer module (see figure). The test-input-generator module automatically generates inputs to the program under test, one at a time, on the basis of a previously developed symbolic-execution approach. In this approach, symbolic values (instead of data) are used to represent program values and the state of a symbolically executed program is represented by a combination of (1) the symbolic values, (2) a program counter, and (3) a path condition in the form of a Boolean formula over the symbolic inputs that accumulate constraints that the inputs must satisfy in order to make execution follow a particular associated path.



**Four Software Modules** are used together to determine (1) what properties the program under test should have and (2) whether it does, indeed, have those properties.

An input generated by the test-input-generator module is fed to the property-generator module, which automatically generates a set of properties that the program under test is required to exhibit when executed in response to the given input. The input is then fed to the program under test. The program is then executed and generates an execution trace.

The instrumentation and observer modules perform the aforementioned run-time analysis. The instrumentation module must be constructed to report events that are relevant for determining whether the program exhibits the required properties during a particular execution. The observer accepts, as input, the execution trace and the set of properties generated by the property-generator module to determine whether the program exhibits the required properties.

The test-input-generator and property-generator modules must be constructed specifically for the program under test. It may be possible to automate the construction of the instrumentation module, depending on the nature of the program under test. The observer module is generic and can be re-used for testing other programs.

*This work was done by Mike Lowry, Willem Visser, and Rich Washington of Ames Research Center; Cyrille Artho of Computer Systems Institute; Allen Goldberg, Klaus Havelund, and Corina Pasareanu of Kestrel Technology; Sarfraz Khurshid of Massachusetts Institute of Technology; and Grigore Roŧlu of the University of Illinois at Urbana-Champaign.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-15244-1.*



## Books & Reports

### **Rover Wheel-Actuated Tool Interface**

A report describes an interface for utilizing some of the mobility features of a mobile robot for general-purpose manipulation of tools and other objects. The robot in question, now undergoing conceptual development for use on the Moon, is the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) rover, which is designed to roll over gentle terrain or walk over rough or steep terrain. Each leg of the robot is a six-degree-of-freedom general-purpose manipulator tipped by a wheel with a motor drive. The tool interface includes a square cross-section peg, equivalent to a conventional socket-wrench drive, that rotates with the wheel. The tool interface also includes a clamp that holds a tool on the peg, and a pair of fold-out cameras that provides close-up stereoscopic images of the tool and its vicinity. The field of view of the imagers is actuated by the clamp mechanism and is specific to each tool. The motor drive can power any of a variety of tools, including rotating tools for helical fasteners, drills, and such clamping tools as pliers. With the addition of a flexible coupling, it could also power another tool or remote manipulator at a short distance. The socket drive can provide very high torque and power because it is driven by the wheel motor.

*This work was done by Jaret Matthews, Norman Ahmad, and Brian Wilcox of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-43308*

### **Second-Generation Electronic Nose**

A report discusses the second generation of the JPL Electronic Nose (ENose), an array of 32 semi-specific chemical sensors used as an event monitor to identify and quantify contaminants released into breathing air by leaks or spills. It is designed to monitor the environment for changes in air quality, and is trained to identify and quantify selected chemical species at predetermined concentrations, ranging from sub-ppm to ppth. This system has improved reproducibility for making matched arrays, allowing use of data analysis software with minimal recalibration on sensor set replacement. The Second Generation (SG) ENose is a follow-up to the first JPL Electronic Nose that was tested on an earlier space shuttle mission (STS-95). Improvements have been made to the hardware, sensor materials, and data analysis software.

The SG ENose can be adapted to different applications and analyte sets by

selection of sensor sets. A monolithic chassis eliminates most fittings, tubing, and dead space, improving the flow system. The SG ENose also includes humidity and temperature sensors in the sensing chamber for improved event deconvolution. The design allows simple and rapid change-out of sensor sets and of filter material. All surfaces exposed to analyte are made of inert materials, and the unit is small enough to be handheld.

*This work was done by Margie Homer, Shiao-Pin Yen, Margaret Ryan, Abhijit Shevade, Hanying Zhou, Adam Kisor, Darrell Jan, April Jewell, Charles Taylor, Allison Manfreda, and Kenneth Manatt of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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